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Contributions to COR science objectives:

- When did the first stars in the universe form, and how did they influence their environments?
- What are the mechanisms by which stars and their planetary systems form?
- How are the chemical elements distributed in galaxies and dispersed in the circumgalactic and intergalactic medium?

This science objective contributes to the above objectives by trying to understand how molecules and dust cores form in massive winds. At high redshifts, evidence is that metal enrichment and dust occurred early after the first stars formed. We simply do not understand how the dust cores form in stellar atmospheres, enriched by carbon and oxygen the basic building blocks for many molecules. Yet molecular and dust formation is so robust that both form even in stars with greatly depleted amounts of carbon and oxygen, as exemplified by Eta Carinae. Massive stars, that evolved rapidly, must play a dominant role in chemical enrichment early in the Universe. By studying current day systems, we can gain insight on the earliest mixing in young galaxies.

How do molecules and dust form in massive interacting winds?

One of the mysteries of interstellar dust is how it forms. While prodigious amounts of dust are seen in the interstellar medium, most models assume a dust core and then proceed to build a mantle of condensed molecules around this core.

What are the sources of the dust cores? Most likely come from relatively cool stars that have evolved over a lengthy period, producing prodigious amounts of carbon and oxygen through the CNO process. However we find massive amounts of dust around evolved massive stars, most notably evolved massive binary systems. The amount of UV and visible radiation should prevent the formation of molecules and dust, yet dust is present. Evolved massive stars with large amounts of carbon and oxygen, as seen, would be expected to form molecules and dust. But how does dust form in massive stars with greatly depleted carbon and oxygen?

Such is the case with the massive binary, Eta Carinae. In the Great Eruption of the 1840s, huge amounts of material were ejected by this very evolved binary. Today that ejecta, know as the Homunculus, expands outward at 600 km/s, and is seen on the sky by reflected starlight… by dust formed at the time of the eruption. The central source, measured to have a luminosity of 5x10^6 solar luminosities, is occulted by five magnitudes, thought to be dust actively being formed in the current interacting winds.

With Herschel, we have found evidence for many molecules despite the fact that carbon and oxygen are depleted nearly 100-fold relative to solar abundances. The identified molecules and their abundances are extraordinarily different from abundances in molecular clouds or ejecta from massive stars with normal abundances. How did dust form in the Great Eruption and continue to form in the interacting winds when carbon and oxygen are so depleted? Is the dust different in composition? Is the dust formation process far more robust that we think?

The Space Telescope Imaging Spectrograph on Hubble, with 0.1” angular resolution and 8000 resolving power, has provided spatial-velocity data cubes of forbidden line emission originated from Fe, N, O, S, Ne at visible wavelengths. Such has inspired very detailed three-dimensional hydrodynamic models of the interacting winds as we attempt to located regions in the compressed winds where molecules and dust might form. At larger scales, the 20”-sized Homunculus has been studied in detail to understand the spatial structure of the expanding material. From Herschel, we have found dozens of molecules in this outer structure that appear to co-exist in either a layered, or clumped, environment. Both the central binary source with its massive interacting winds and the expanding Homunculus are evolving noticeably with time.

Selected HST/STIS forbidden line data cubes have been matched with synthetic emission data cubes derived from the three-dimensional hydrodynamic models at specific phases of the 5.5-year binary period, As the forbidden line emission is dependent upon FUV radiation and critical densities, we are able to probe the interacting winds and with the models, we are able to isolate compression regions, that, with radiative transfer, indicate where the densities and temperatures would promote molecular and dust formation.

Three areas of improvement are necessary to dig deeper into this problem:

1) Higher spatial resolution. Factors of 2 – 10 would lead to improved definition of regions where molecules and dust form. The binary orbit is thought to have a 0.010” semi-major axis (and the interacting winds serve as a major amplifying factor to the scale that HST/STIS resolves the winds). The compression regions should have scales of this amplitude.
2) Improved throughput throughout the visible and UV. HST/STIS, because of desire to have diffractive-limit spatial resolution and the corrective optics, required multiple reflective surfaces. Improved optical design, potentially totally different photonics designs (fiber optic concepts??), and improved reflectivity must be developed.
3) Multi-aperture optical system and larger format visible/UV detector. HST/STIS, with its imaging capability and long slit designs provided the ability to map complex systems such as the interacting winds. However, building a 2.4”x2.4” map with 0.1” spatial resolution, optimally sampled at 0.05”, required nearly a full HST CVZ orbit for individual 30 second exposures.